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METHODS FOR DETERMINING

THE

DENSITY AND SPECIFIC GRAVITY

OF

COAL GAS.

By WILLIAM W. GOODWIN,
Author of the History and Principles Involved in the Use of Lowe's Jet Photometer.

PUBLISHED BY WM. W. GOODWIN & CO.,
GAS METER MANUFACTURERS,
1012, 1014, and 1016 FILBERT STREET,
PHILADELPHIA, PA.
1875.

WM. WALLACE GOODWIN. HOWARD KIRK, SPECIAL PARTNER.

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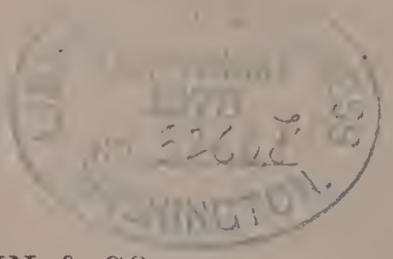

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DENSITY AND SPECIFIC GRAVITY OF GASES.

In presenting the following methods for determining the Density and Specific Gravity of Coal Gas, the author does not desire to lay claim to any new methods for determining the same, but rather to present, in as concise a form as possible, consistent with a proper understanding of the subject, the principles, and the several methods in use for the purpose, and to call attention to an instrument designed by him for arriving at the Density and Gravity of Coal Gas, by what is known as the Effusion Method, the simplicity of which, he feels confident, must recommend itself. In compiling the following pages, the author acknowledges his indebtedness to 'Fresenius's' and 'Fowne's Chemistry,' 'Bunsen's Gasometry,' and 'Sugg's Gas Manipulations.' He trusts his efforts may be the means of directing the attention of Gas Engineers to the fact that the Density and Gravity of Coal Gas have to do with its quality and illuminating power. It is an established fact that, if Coal Gas is free from carbonic acid and air, specific gravity is a proper test of quality as well as an approximate test of its illuminating power, because the carbon vapors increase the weight of a given volume on which its light-giving power depends.

Numerous experiments led Mr. Clegg to assert that the illuminating power is almost directly as the specific gravity, viz., if the specific gravity .300 gives six candles, .500 gives the light of ten.* Specific gravities of Coal Gas vary from .340 to .600. Carbonic acid and air increase the weight, and when present greatly diminish the luminosity of the flames, in which case the specific gravity cannot be relied upon.

* The author does not wish to be understood as asserting the correctness of this theory, but only as calling attention to the conclusion arrived at by Mr. Clegg after numerous experiments.

It is of great importance to understand clearly what are meant by the terms *density* and *specific gravity*—two terms which are constantly confounded in the ordinary use of language. By the *density of a body*, is meant its *mass*, or *quantity of matter* compared with the mass or quantity of matter of an *equal volume* of some standard body arbitrarily chosen. *Specific gravity* denotes the *weight* of a body, as compared with the weight of an equal bulk or volume of the standard body, which is reckoned as unity.* In all cases of *solids* and *liquids* the standard of unity adopted in this country is pure water at the temperature of 60° Fahr. For coal gas *air* is used as a standard of comparison. These articles are taken for the sake of convenience, being always at hand, and easily obtained in a state of comparative purity. An ordinary expression of specific weight, therefore, is a number explaining how many times the weight of an equal bulk of water is contained in the weight of the substance spoken of. If, for example, we say that concentrated oil of vitriol has a specific gravity equal to 1.85, or that perfectly pure alcohol has a density of 0.794, we mean that equal bulks of these two liquids, and of distilled water, possess weight in the proportion of the numbers 1.85, 0.794, and 1, at 60° Fahr. It is necessary to be particular about the temperature, for liquids are extremely expansible by heat; otherwise a constant bulk of the same liquid will not retain a constant weight.

It requires some little abstraction of mind to realize completely the condition in which all things at the surface of the earth exist. We live at the bottom of an immense ocean of gaseous matter, which envelops everything, and presses upon everything with a force which appears, at first sight, perfectly incredible, but whose actual amount admits of easy proof. Gravity being, as far as is known, common to all matter, it is natural to expect that *gases*, being material substances, should be acted upon by the earth's attraction as well as *solids* and *liquids*. This is really the case, and the result is the weight or pressure of the atmosphere,

* In other words, density means comparative *mass*, and specific gravity comparative *weight*. These expressions, although really relating to distinct things, are often used quite indifferently in chemical writings, and without practical inconvenience, since mass and weight are directly proportional to each other.

which is nothing more than the effect of the attraction of the earth on the particles of air.

In describing the leading phenomena of the atmospheric pressure, it is necessary to notice one very remarkable feature in the physical constitution of gases, upon which depends the principle of an extremely valuable instrument, the air-pump, viz., gases are in the highest degree *elastic;* the *volume* or *space* which a gas occupies *depends upon the pressure exerted upon it*—that is to say, the volume of gas is *inversely* as the pressure; the density and elastic force are *directly* as the pressure, and *inversely* as the volume.

For instance, 100 cubic inches of gas under a pressure of 30 inches of mercury, would expand to 200 cubic inches were the pressure reduced to one-half, and shrink on the contrary to 50 cubic inches, if the original pressure were to be doubled. The change of density must necessarily be in the inverse proportion to that of the volume, and the elastic force follows the same rule.

To determine with the utmost degree of accuracy the specific gravity of a gas, is an operation of very great practical difficulty, but, at the same time, of very great importance. There are several methods which may be adopted for the purpose. The one described below requires the most scrupulous care, and the observance of a number of minute precautions which are absolutely indispensable to success.

The plan of operation is as follows:—

A large glass globe is to be filled with the gas to be examined, in a perfectly pure and dry state, having a known temperature, and an elastic force equal to that of the atmosphere at the time of the experiment. The globe so filled is to be weighed. It is then to be exhausted at the air-pump as far as possible, and again weighed. Lastly, it is to be filled with dry air, the temperature and pressure of which are known, and its weight once more determined. On the supposition that the temperature and elasticity are the same in both cases, the specific gravity is at once obtained by dividing the weight of the gas by that of the air.

Mr. Sugg, in treating of this subject, describes two processes employed for determining the specific gravity of a gas: first by means of a glass globe. To carry out this experiment accurately, he says that

a good air-pump is absolutely necessary; a very light globe of hard German glass is provided with a stopcock at each end. The capacity of this ball is about 100 cubic inches. Having adjusted the balance, weigh the globe accurately to the fractional part of a grain, and then remove it to the air-pump; exhaust the air, weigh it again, and the number of grains and tenths of a grain represents the weight of the air abstracted. Suppose it takes 31; now fill the ball with gas from the gas-holder, remove it and weigh it again; and the number of grains represents the weight of the gas introduced. Suppose it takes thirteen; then—

As 31 : 13 :: 1.000
13

31)13.000(.419 *Answer.*
12 4

60
31

290
279

11

The specific gravity of the gas is therefore .419, air being taken at 1.000; and as 100 cubic inches of pure and dry atmospheric air weigh at mean temperature and pressure 31.0117 grains, the weight of 100 inches of the gas can be easily determined; for—

As 1.000 : .419 :: 31.0117
.419

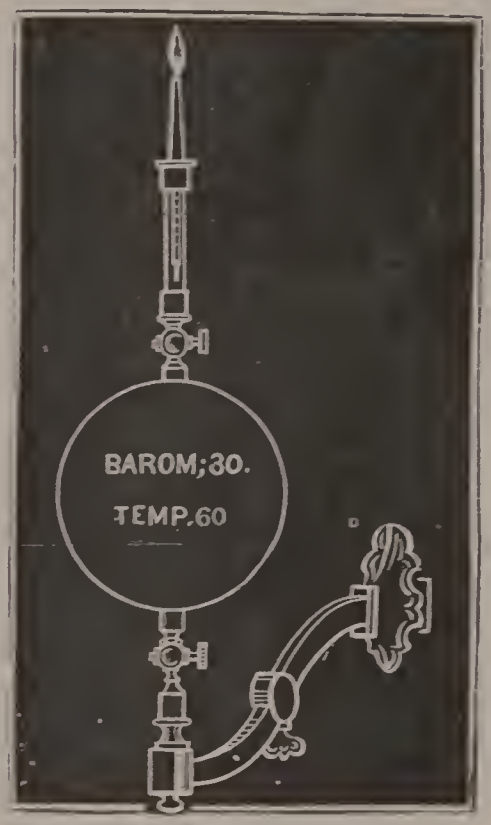
2791053
310117
1240468

1.000)12.9939023

12.9939 *Answer.*

That is, the specific gravity of air is to the specific gravity of the gas what the weight of 100 inches of air is to the weight of 100 inches of the gas, and from this result the weight of any quantity of the gas can of course be determined.

Dr. Letheby's method of ascertaining the specific gravity of gas is as follows: He uses a glass globe of about six inches in diameter, with a double neck. The two necks are opposite each other, and are fitted with small caps and very small stopcocks. One of the stopcocks screws into a gas-pillar, and so supports the globe; the other carries a cap, with a glass tube about one-half an inch in diameter and seven inches long. This tube contains a thermometer, and is fitted at the opposite end with a jet for burning the gas. (See figure.) The globe with the stopcock attached, but without the tube, is accurately balanced while in an exhausted state, and a counterpoise weight is provided. The exact weight of the globe, when full of air at 60° Fahr. and thirty inches barometrical pressure, is ascertained, and engraved on the globe.



In practice the globe is always attached to the gas-pillar, and therefore gas is constantly passing through it, so that it is always full of gas ready for weighing. When the specific gravity is required, the gas is shut off by first turning the *lower* stopcock, and then a moment after the upper one, so that the globe at the time of weighing has not the contained gas at the pressure in the main, but at the atmospheric pressure; it is then suspended from the beam of the balance, and its exact weight determined. By the simple rule of three the specific gravity of the gas is ascertained. For instance, say the weight of the globe, when full of air, is sixty grains more than the counterpoise of the globe in its exhausted state, and that when it is taken from

the gas-pillar, and is full of gas, the weight of the globe is twenty-five grains; then, as 60 : 1.000 (the specific gravity of air) :: 25 : .416 (the specific gravity of the gas).

This example is worked out thus:—

Weight of the globe in grains when full of air.		Standard specific gravity of air.		Weight of the globe in grains when filled with gas.
60	:	1.000	: :	25

1.000

60)25.000

.416 *Answer.*

Correction is then made for temperature and barometric pressure.

The advantage of this apparatus is, that it requires no exhausting by an air-pump, but is always ready for experiment. To operate successfully, however, with either form of apparatus described, access to a very delicate balance is indispensable.

The author will now call attention to the Effusion Method.

The rates of *effusion* of gases, that is to say, their rates of passage through a minute aperture in a thin plate of metal or other substance into a vacuum, follow the same law as their rates of diffusion, that is to say, they are inversely as the square roots of the densities of the gases. Nevertheless, the phenomena of Diffusion and Effusion are essentially different in their nature, the effusive movement affecting masses of a gas, whereas the diffusive movement affects only molecules; and a gas is usually carried by the former kind of impulse with a velocity many thousand times greater than by the latter. *Mixed gases are effused at the same rate as one gas of the actual density of the mixture;* and no separation of the gases occurs, as in *diffusion* into a vacuum.

The law of effusion just stated is true only under the condition that the gas shall pass through a minute aperture in a very thin plate. If the plate be thicker, so that the aperture becomes a tube, very different rates of efflux are observed; and when the capillary tube becomes considerably elongated, so that its length exceeds its diameter at least four

hundred times, the rates of flow of different gases into a vacuum again assume a constant ratio to each other, following, however, a law totally distinct from that of effusion. The principal general results observed, with relation to this phenomenon of "Capillary Transpiration," are as follows:—

1st. The rate of transpiration of the same gas increases, other things being equal, directly as the pressure; that is to say, equal volumes of gas, at different densities, require times inversely proportional to their densities.

2d. With tubes of equal diameter, the volume transpired in equal times is inversely as the length of the tube.

3d. As the temperature rises, the transpiration of equal volumes becomes slower.

4th. The rates of transpiration of different gases bear a constant relation to each other, totally independent of their densities, or indeed of any known property of the gases. Equal *weights* of oxygen, nitrogen, and carbon monoxide* are transpired in equal times; so likewise are equal weights of nitrogen, nitrogen dioxide,* and carbon monoxide; and of hydrogen, chloride, carbon dioxide,* and nitrogen monoxide. In other words, this method is based on the fact that the specific gravity of two gases which stream out of a fine opening in a thin plate, are very nearly proportional to the square of the time of effusion. If a gas of specific gravity S requires the time t, and another gas of specific gravity S_1 requires the time t_1, the relation between the times of effusion and the specific gravities is represented by the equation $\frac{S_1}{S} = \frac{t_1^2}{t^2}$. If S, or the specific gravity of one gas, be made equal to 1, the specific gravity of the

* Composition.

	By weight.		By volume.	
	Carbon.	Oxygen.	Carbon.	Oxygen.
Carbon monoxide [*i. e.*, carbonic oxide]	12	16	1	1
Carbon dioxide [*i. e.*, carbonic acid]	12	32	1	2
	Nitrogen.		Nitrogen.	
Nitrogen monoxide [*i. e.*, nitrous oxide]	28	16	2	1
Nitrogen dioxide [*i. e.*, nitric oxide]	28	32	2	2

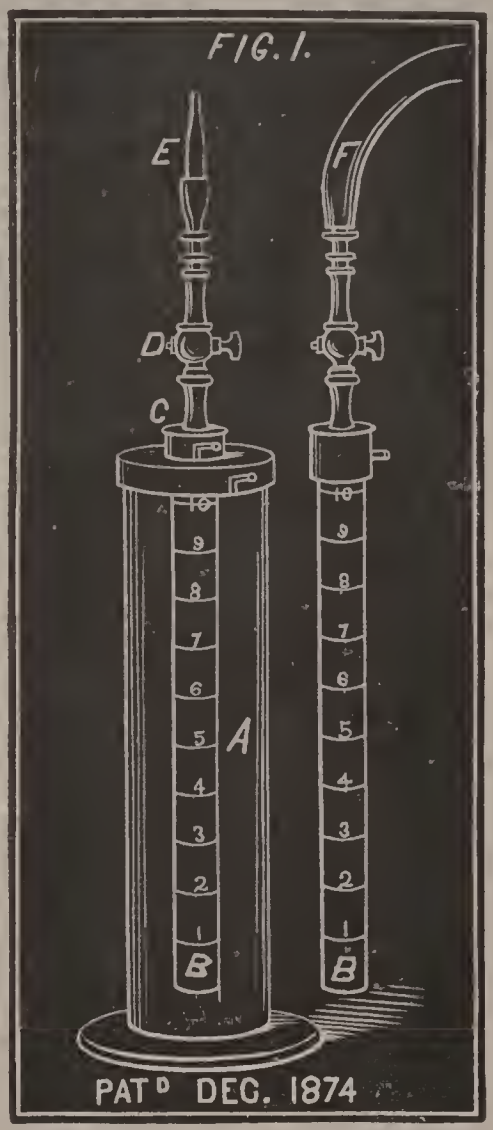
other is found from the formula $S_1 = \frac{t_1^2}{t^2}$. Thus, it will be seen that by means of this method the time of effusion of a column of gas is obtained having a constant length on a tube, and issuing under pressures the sum of which remains always constant. This time of effusion, determined for various gases, raised to the square, gives the relation of the specific gravities of the gases. The following experiments show the degree of accuracy which can be attained by this method. The first column t contains the times of effusion of a volume of air; the second column t_1 the times of effusion of an equal volume of gas; the third and fourth columns the square of these observed times; and the fifth column the specific gravities calculated from these squares.

Air. t.	Hydrogen. t_1	t^2.	t_1^2.	$\frac{t_1^2}{t^2}$
105.5	29.7	11130	882.09	0.0792
105.0	30.0	11025	900.00	0.0816
105.5	29.5	11130	870.25	0.0782
105.6	29.3	11151	858.49	0.0770
105.5		11130		

The mean specific gravities, calculated from a number of experiments, are collected in the following table. The first column contains the experimental results; the second column the same values calculated from atomic weights.

Gases.	I.	II.	Difference.
Air	1.000	1.000	
Carbonic acid	1.535	1.520	+0.015
1 Vol. CO+1 vol. CO^2	1.203	1.244	—0.041
Oxygen	1.118	1.106	+0.012
Electricity deton. gas	0.414	0.415	—0.001
Hydrogen	0.079	0.069	+0.010

It is seen that the agreement between the experimental, and the calculated values, is very close. For technical purposes, as for instance, the determination of the specific gravity of coal gas, this method is peculiarly applicable from its extreme simplicity. The author has designed a form of apparatus, based upon the foregoing method, the object of which is to simplify and render less costly, without diminishing materially the accuracy of, the apparatus for taking the density or specific gravity of coal and other gases, by the efflux of the same through a fine opening in a thin plate of metal. The figure exhibits the apparatus. A is a glass jar or water-holder; B is a glass tube divided into a number of equal parts for measuring gas; C is a movable cap; D is a stopcock attached to tube B; E is the top, containing the orifice for the effusion of gas; F rubber hose attached to tube B.



The apparatus is prepared for operation by detaching and withdrawing the tube B, and pouring water into the vessel A, in sufficient quantity to bring its surface up to about, or a little above, the upper line of the glass tube B; on introducing the latter, and securing it by the catch, the stopcock D being at the same time closed, the air in the tube B will be confined therein.

The apparatus being thus made ready, the operator, with stop-watch in hand, opens the stopcock D. The air in B slowly escapes through the minute orifice in the metal plate on the top of the tip E; when the rising water reaches the number 1 line on the glass tube B, he starts his stop-watch, and carefully observing the rising water, stops his watch the instant the surface line of the water

reaches, say, the highest number 10, and notes the *time* occupied by the effluxion of the nine inches of *air*.

The operator now detaches the tip E, and inserts the end of stopcock D into the end of a rubber tube E, and passes a current of the gas to be tested, down through B until the atmospheric air is driven out, and its place occupied by the gas only, then closes the stopcock D, detaches the rubber hose, and reinserts the tip E as before. Now, with his stop-watch in hand, he opens the stopcock and starts his watch the instant the surface line of the water in B reaches 1, and carefully observing the rising water, stops his watch the instant the surface line of the water reaches the line numbered 10, and notes the *time* occupied by the effluxion of the nine inches of *gas*. He now *squares the time* required for *each* of the fluids to pass through the orifice, and *divides the square of the gas by the square of the air*. The *result* is the *density* or *specific gravity* of the gas.

For example, suppose the time of effusion of air equalled 139 seconds, and for gas 90 seconds, then, according to the formula given, $S_1 = \frac{t_1^2}{t^2}$; the specific gravity of the gas is found by dividing the square of the time of effusion of the gas by the square of the time of effusion of the air, thus $\frac{\text{gas time}^2}{\text{air time}^2} =$ specific gravity of the gas.

The air flowed through the orifice in 139 seconds. Gas flowed out in 90 seconds, therefore—

$$\frac{\text{Gas time}^2}{\text{Air time}^2} = \frac{90^2}{139^2} = .419.$$

Square of air time. Square of gas time.

19321)8100.0(.419 specific gravity.

77284

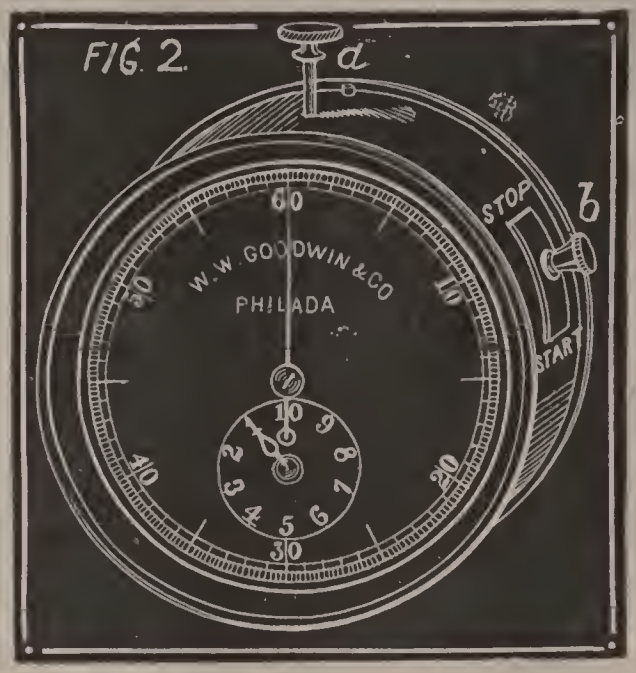
37160

19321

178390

173889

The instrument should be read from *lowest* part or curve of the water, called the *meniscus*. Its accuracy may be shown with either olefiant or hydrogen gases, the true specific gravity of olefiant gas being 0.981, and that of *pure* hydrogen 0.0695. The tip should be covered when not in use, as dust soon clogs it if left exposed.



The Fig. represents a stop-watch which is furnished with the instrument when desired, and is so constructed that, after starting the timer by placing the finger on the button A, the hands instantly return to zero, and remain in that position until the finger is removed. The timers are also useful for photometrical and burner tests. Each is warranted, and furnished in a small velvet-lined box. Annexed are tables of squares from 50 to 200 seconds, which can be used in the tests.

Seconds.	Squares.	Seconds.	Squares.	Seconds.	Squares.
50	25 00	62	38 44	74	54 76
51	26 01	63	39 69	75	56 25
52	27 04	64	40 96	76	57 76
53	28 09	65	42 25	77	59 29
54	29 16	66	43 56	78	60 84
55	30 25	67	44 89	79	62 41
56	31 36	68	46 24	80	64 00
57	32 49	69	47 61	81	65 61
58	33 64	70	49 00	82	67 24
59	34 81	71	50 41	83	68 89
60	36 00	72	51 84	84	70 56
61	37 21	73	53 29	85	72 25

Seconds.	Squares.	Seconds.	Squares.	Seconds.	Squares.
86	73 96	119	1 41 61	152	2 31 04
87	75 69	120	1 44 00	153	2 34 09
88	77 44	121	1 46 41	154	2 37 16
89	79 21	122	1 48 34	155	2 40 25
90	81 00	123	1 51 29	156	2 43 36
91	82 81	124	1 53 76	157	2 46 49
92	84 64	125	1 56 25	158	2 49 64
93	86 49	126	1 58 76	159	2 52 81
94	88 36	127	1 61 29	160	2 56 00
95	90 25	128	1 63 84	161	2 59 21
96	92 16	129	1 66 41	162	2 62 44
97	94 09	130	1 69 00	163	2 65 69
98	96 04	131	1 71 61	164	2 68 96
99	98 08	132	1 74 24	165	2 72 25
100	1 00 00	133	1 76 89	166	2 75 56
101	1 02 01	134	1 79 56	167	2 78 89
102	1 04 04	135	1 82 25	168	2 82 24
103	1 06 09	136	1 84 96	169	2 85 61
104	1 08 16	137	1 87 69	170	2 89 00
105	1 10 25	138	1 90 44	171	2 92 41
106	1 12 36	139	1 93 21	172	2 95 84
107	1 14 49	140	1 96 00	173	2 99 29
108	1 16 64	141	1 98 81	174	3 02 76
109	1 18 11	142	2 01 64	175	3 06 25
110	1 21 00	143	2 04 49	176	3 09 76
111	1 23 21	144	2 07 36	177	3 13 29
112	1 25 44	145	2 10 25	178	3 16 84
113	1 27 69	146	2 13 16	179	3 20 41
114	1 29 96	147	2 16 09	180	3 24 00
115	1 32 25	148	2 19 04	181	3 27 61
116	1 34 56	149	2 22 01	182	3 31 24
117	1 36 89	150	2 25 00	183	3 34 86
118	1 39 24	151	2 28 01	184	3 38 56

Seconds.	Squares.	Seconds.	Squares.	Seconds.	Squares.
185	3 42 25	191	3 64 81	196	3 84 16
186	3 45 96	192	3 68 64	197	3 88 09
187	3 49 69	193	3 72 49	198	3 92 04
188	3 53 44	194	3 76 36	199	3 96 01
189	3 57 21	195	3 80 25	200	4 00 00
190	3 61 00				

TABLE.

(Newbigging's.)

Comparing the Specific Gravity of Gas (air being 1.000*) with the Illuminating Power in Standard Sperm Candles—assuming that the Gas is pure.*

No. of Candles.	Specific Gravity.	No. of Candles.	Specific Gravity.
10 equal to about	.380	24 equal to about	.565
11 " "	.392	25 " "	.585
12 " "	.405	26 " "	.605
13 " "	.406	27 " "	.625
14 " "	.430	28 " "	.645
15 " "	.443	29 " "	.662
16 " "	.455	30 " "	.678
17 " "	.468	31 " "	.694
18 " "	.482	32 " "	.708
19 " "	.495	33 " "	.722
20 " "	.508	34 " "	.738
21 " "	.522	35 " "	.755
22 " "	.537	36 " "	.775
23 " "	.550	37 " "	.790

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PHOTOMETRICAL APPARATUS of every description.

GOODWIN'S IMPROVED BUNSEN, LETHEBY ELECTRICAL PHOTOMETER.—This instrument extinguishes the gas and candle, stops the meter and clock at any moment desired, either by time, gas, or candle. Patented Dec. 22, 1874.

GOODWIN'S IMPROVED LOWE'S JET PHOTOMETER.—This instrument shows the candle power and pressure required for same on dial. Patented April 22, 1873; re-issued Jan. 26, 1875. All other candle power dials are infringements.

GOODWIN'S ELECTRICAL PHOTOMETER BALANCE for weighing candles *in sitû*. Patented Jan. 12, 1875.

GOODWIN'S DENSITY AND SPECIFIC GRAVITY APPARATUS for determinations by the Effusion Method. Patented Dec. 15, 1874.

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